Design of Deep Subwavelength Antennas of VLF Communications

Amarachukwu Nzedibe, *Student Member, IEEE*, Linda Katehi, *Member, IEEE*

***Abstract*—The high penetration ability if low frequency waves makes VLF antennas vital, but limited in portability due to their large sizes. This project is based on prior research using piezoelectricity to lower an antenna's resonant frequency, drastically decreasing the size of VLF antennas. This report describes the effect of the dielectric constant of an antenna on the resonant frequency. This serves as a proof of concept to be built upon through further research.**

***Index Terms*—Piezoelectric antennas, electrically small antennas**

I. INTRODUCTION

ANTENNAS for very low frequency applications are sized in the order of a wavelength. Antennas that radiate at lower frequencies are very important when it comes to communication due to the high penetration ability of the waves produced. Such antennas have been used to send and receive signals across global distances as well as penetrate seawater to communicate with underwater vehicles. Due to the importance of these antennas, finding a solution to the size of these antennas has been a topic of interest. Different solutions have been developed, but in this project, the effects of piezoelectricity are considered. Piezoelectricity entails the conversion of energy from the mechanical domain to the electrical domain and vice versa. When a force is applied to a piezoelectric material, an electric current is induced. In the same way, when an electric current is applied, mechanical deformation is achieved. The latter application was used by Kemp and colleagues in their paper on piezoelectric antennas [1]. They designed an antenna that radiated at acoustic wavelengths. Antennas that radiate at lower frequencies are very important when it comes to communication due to the high penetration ability of the waves produced, making it very important to provide a solution to the size of the antennas, a problem that Kemp and colleagues set put to solve. They successfully designed an antenna using a lithium niobate crystal rod with a height of 9.4cm and a diameter of 1.6cm. They fed this antenna with a modulated signal and optimized the antenna for better performance. Their antenna was able to radiate at 35kHz, an incredible feat.

This report observes the effect of the dielectric constant of the material on the resonant frequency of the antenna which will later be observed in conjunction with the piezoelectric effects of the material used.

Amarachukwu Nzedibe is pursuing a master’s degree at Texas A&M University under the supervision of Dr. Linda Katehi.

II. PROCEDURE AND RESULTS

The antenna observed is based on one developed by Kemp and colleagues and designed using the same length (9.4cm) and diameter (1.6cm). However, the design was changed to include a 0.5mm wire immersed in the dielectric as shown in Fig. 1. This wire allows the antenna structure to mimic a typical dipole antenna. To characterize and observe the behavior of this antenna, the dielectric constants corresponding to those of different piezoelectric materials, as shown in Table 1, were varied. The efficiency of the antenna was observed by changing the lengths of the antenna to get resonance at 1GHz.

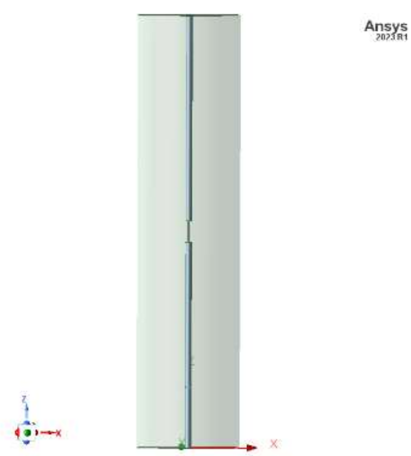

Fig. 1. Model of Dipole Antenna

TABLE I
Dielectric Constants of Piezoelectric Materials

Material	Dielectric constant
Quartz	4.6
Lithium Niobate	85.9
Barium Titanate	1200

A. Effect of Changes in Dielectric Constant (ε_r)

Keeping the antenna at a constant length of 9.4cm, the relative permittivity of the surrounding material was varied.

As seen in Fig 2, the dielectric constant increased, the operating frequency of the antenna shifted downward. This is because the increased permittivity of the surrounding medium effectively increases the electrical length of the dipole. Fig. 2

shows a plot of three different dielectric constants, and as expected, the resonances shift to lower frequencies as the dielectric constant increases.

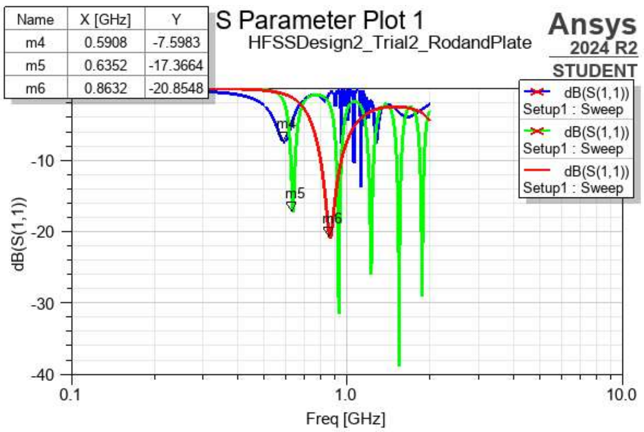

Fig. 2. S-parameter plot showing the resonant frequencies of $\varepsilon_r = 1$, $\varepsilon_r = 4.6$, $\varepsilon_r = 85.9$

To further study the effects of changing the dielectric constant, the length of the antenna was changed in accordance with ε_r.

B. Effects of Changes in Length

The operating frequency was set to 1GHz. In free space ($\varepsilon_r = 1$), the length of a halfwave dipole would be ~15cm. When the dielectric constant of the surrounding medium is no longer equal to 1, the wave length decreases according to (1) and the antenna begins to resonate at a lower frequency. To compensate for this decrease in resonant frequency, the length of the antenna was decreased using (2). This led to increased losses in the antenna, reflected as a decrease in radiation efficiency as shown in Fig. 3.

Table II gives the different dimensions of the antenna.

$$\lambda = \frac{c}{f_c\sqrt{\varepsilon_r}} \tag{1}$$

$$l = \frac{\lambda}{2} \tag{2}$$

TABLE II
Antenna Dimensions

Dielectric Constant	Length of Dipole and Dielectric (cm)	Radius of Dipole (cm)	Radius of Dielectric (cm)
4.6	7	0.05	0.8
85.9	1.6	0.05	0.8
1200	0.43	0.05	0.8

After varying the length, the efficiency as seen in Fig. 3 decreases drastically as the dielectric constant was increased. This could be due to the decreased size of the antenna and mismatch loss. This result is similar to the results in [2] for a changing dielectric.

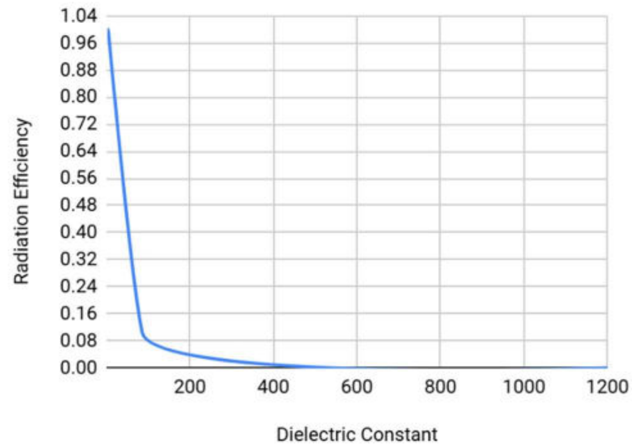

Fig. 3. Plot of the radiation efficiency vs. Dielectric constants

III. CONCLUSION

This project explores how the dielectric constants of materials affect the resonance and radiation efficiency. As expected, losses increase as the relative permittivity of the surrounding medium increases. This phenomenon, in future research can be mitigated through more efficient matching techniques and explored to determine how by using dielectric constants in conjunction with piezoelectricity we can reach even lower frequencies in the kHz range.

IV. FUTURE PLANS

I intend to continue this project to explore piezoelectricity. Due to issues with feeding the antenna when fabricated, I will explore designing planar antennas as part of my master's thesis. I plan afterwards to go into industry and apply my experience.

V. ACKNOWLEDGEMENT

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VI. REFERENCES

[1] M. A. Kemp et al., "A high Q piezoelectric resonator as a portable VLF transmitter," *Nature Communications*, vol. 10, no. 1, Apr. 2019, doi: https://doi.org/10.1038/s41467-019-09680-2.

[2] V. T. Nguyen, C. W. Jung, "Impact of Dielectric Constant on Embedded Antenna Efficiency," *International Journal of Antennas and Propagation*, vol. 2014, pp. 1–6, Jan. 2014, doi: https://doi.org/10.1155/2014/758139.